

ON THE PRODUCTION OF FERTILE HYBRIDS FROM CROSSES BETWEEN
VULGARE AND KHAPLI EMMER WHEATS.

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(Plates iii-iv.)

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Introduction.

Crosses between common wheats (*Triticum vulgare* L.) having 21 pairs of chromosomes and other species having 14 pairs can sometimes be made with comparative ease, but extreme difficulty is encountered in other cases. Some members of the emmer group (*T. dicoccum* Schrnk.) fall within this latter category. An outstanding example is the Indian emmer known as "Khapli". Botanically it is a member of the group *T. dicoccum* Ajar Perc. From a commercial wheat-growing point of view it is unimportant, but it is a remarkable wheat for its extreme resistance to disease. There are few varieties showing this quality to the same degree.

On account of its disease resistance, many efforts have been made to cross "Khapli" with *vulgare* wheats. Puttick (1921) found that crosses with "Marquis" (*T. vulgare*) gave only sterile plants. Hayes and Stakman (1922) reported disappointing results from attempts to make the same crosses. Hynes (1926) described work giving fertile F₁ plants from crosses between "Federation" and "Khapli". Thompson and Hollingshead (1927) secured grain from crosses with *vulgare* wheat, but no fertile plants resulted. Waterhouse (1930) reported similar failure in an extensive series of crosses between *vulgare* wheats and "Khapli". Hollingshead (1932) failed when using "Federation", but met with a measure of success from using as the *vulgare* parent a wheat which had been produced by McFadden (1930) from a cross between a *vulgare* and an emmer wheat.

There is a further record which does not appear to have been published. In communications to the writer under date 22nd September, 1929, and 23rd September, 1930, the Economic Botanist of the Central Provinces of India has stated that certain *vulgare* wheats in cultivation there have been derived from crosses between "Murya", a common wheat, and "Khapli" emmer. He kindly forwarded grain of these wheats. They have been grown and it is found that this "Khapli" is totally different from the "Khapli" obtained from Dr. E. C. Stakman of Minnesota under the C.I. Number 4013, the strain used by the other workers. It falls within a different subspecies, having pubescent chaff and black awns.

Obviously this Indian crossing work involves a totally different parent. It may be remarked that crosses between "Federation" and this emmer have given sterile F₁ plants similar to those reported for the true "Khapli" crosses. The same result has been obtained when "Murya" has been crossed with the true "Khapli".

Further "Khapli" Crosses.

Since the summarizing of the writer's previous work (Waterhouse, 1930) up to the 1927 season, further "Khapli" crosses have been made each year. A recent striking success makes it wise to report the results at this stage, although the investigations are still in progress.

Having consideration to the possible effect that seasonal variations may have upon the results of crossing, certain *vulgare* parents—and notably "Federation"—have been used year after year. Whilst there have been some differences in the number of grains set, in their plumpness and in the amount of growth made, the characters of the F₁ plants have not appreciably varied from season to season. In all cases they have been completely sterile "grass clumps" when "Federation" has been used.

The results to date in respect to the grain setting from the crosses made are summarized in Table 1.

TABLE 1.

Summary of results obtained from crosses between vulgare and "Khapli" wheats.

Year of Crosses.	Number of Grains Set.	Number of Flowers Pollinated.	Percentage Grain-Setting.
*1921 to 1927	286	1,860	15
1928	29	118	25
1929	197	654	30
1930	64	136	48
1931	633	1,278	50
1932	618	1,134	54
Totals	1,827	5,180	

* Vide PROC. LINN. SOC. N.S.W., 55, Part 5, p. 605.

The average grain-setting for the period amounts to 35%. In the earlier years "Federation" and "Hard Federation" were extensively used, but more recently only 1 or 2 heads of these varieties have been pollinated each season. The increase in the grain-setting in later years is mainly due to the use of other *vulgare* wheats which cross somewhat more readily with "Khapli".

The varieties of *vulgare* wheat which have been used to date in the crosses with "Khapli" are as follows:

Akacomoughi	Etawah	(Indian F × Telford's)
Anchor	Exquisite	Kenya Crossbred C6041
Aussie	Federation	" " C6042
Baroota Wonder	(Federation × Khapli)	Kenya Governor
Bearded Gluyas	Felix	King's Early
Bena	Firbank	Linden
Bobin	Florence	Little Club
Bobs	Ford	Mac's White
Bomen	Free Gallipoli	Maharajah
Bunge	Gallipoli	Marquillo
(Bunge × Emmer 19)	Garra	Murya
Bunyip	Geeralying	(Murya × Khapli)

Canberra	Gem	Nabawa
Cedar	Gluyas	No. 76
Clarendon	Gresley	Penny
Clubhead	Guinea	(Purple Straw × Medeah)
Comeback	Gullen	Quantity
Crossbred W519	Hard Federation	Queen Fan
" W522	Hope	Riverina
Currawa	Hornbill	(Stanley × Yandilla King)
Dindiloa	(Huguenot × Federation)	Steinwedel
Dundee	(Huguenot × Fed'tion × Fed'tion)	Sunset
Duri	Hurst's 11	Thew
Early Bird	Improved Steinwedel	Waratah
Early Defiance	Indian F	Yandilla King
(Emmer × Marquis)	Indian 12	Zaff

Certain of these crosses were actually made by Messrs. J. H. Kaye and J. Bolin, whose help has been loyally given out of their own time and is gratefully acknowledged. The first of the Steinwedel and Improved Steinwedel crosses were actually made by the former.

It was early considered that *vulgare* wheats owing their origin to crosses involving wheats with 14 pairs of chromosomes might cross with "Khapli" more readily than other *vulgares*. All available wheats of this nature have been tried, as the above list shows.

The results have been extremely variable. The crossed grain in some cases has been tiny and pinched, in others large and plump. The grain has failed to germinate in some instances. In others the F_1 plants have been tiny "grass clumps" which have soon died. All the intermediate stages have been found between these and fairly well grown plants up to 3 feet high and showing a low degree of fertility. With the three exceptions to be described presently, all have shown notable stunting and yellowing, followed by early death, even under conditions of careful cultivation and watering. This extreme chlorosis has been a striking feature.

Seedling tests of these F_1 plants have been made with three physiologic forms of *Puccinia graminis tritici*. With Forms 43 and 46 there has been an approach to complete dominance of resistance. With Form 34 the approach has been to dominance of susceptibility. Flag smut tests have shown dominance of resistance.

The *vulgare* parents of the crosses in which the F_1 plants have produced a grain or grains are as follows: Anchor, Bunyip, Canberra, Crossbred W519, Exquisite, Florence, Free Gallipoli, Garra, Geeralying, Gresley, Gullen, Hornbill, Improved Steinwedel, Linden, Marquillo, Riverina, Steinwedel, Zaff.

These include one or two cases in which pollen of the *vulgare* parent was used to pollinate the F_1 stigmas, in addition to those in which open-pollination took place.

An examination of the available pedigrees of these varieties has been made. It shows that seven out of the eighteen which gave fertile progeny are derivatives of crosses involving *T. durum*. On the other hand it is found that ten of the sixty parents which produced sterile F_1 plants were *durum* or *dicoccum* derivatives, including a "fixed" *vulgare* wheat from the (Federation × Khapli) cross reported by Hynes, and "Hope", a *dicoccum* derivative.

From certain of the crosses—notably when "Bobin", "Gullen" and "Geeralying" are the *vulgare* parents—material is now in the F_3 generation. Extremely wide segregation is being shown. Analysis is not complete, but seemingly there is a paucity of *vulgare* types.

The grain-setting by the F_1 plants under conditions of open-pollination is low. Thus in 1932, which was a good season, 153 grains were produced from 224 F_1 plants of 11 different *vulgare* and "Khapli" crosses.

It will be seen that the fertility of these crosses has been low and the advance made in the problem not very great.

Higher Fertility Crosses.

In addition to considering the likelihood of *durum* or *dicoccum* parentage in *vulgare* wheats contributing to ease of crossing, those varieties like "Bobin" and "Gullen" which gave a small measure of fertility were studied in regard to their parentage. Where possible the ancestors of these wheats were used in further crosses with "Khapli", together with other varieties in whose pedigrees these same ancestors appeared. Of course there were others in which there was merely haphazard selection of the *vulgare* parent. But the success gained is traceable to the choice of wheats entering into the pedigree of those which had earlier given some slight fertility.

In 1931 "Garra", "Improved Steinwedel", and "Steinwedel" were pollinated with "Khapli" pollen. Unusually plump grain was set to the extent of about 65%, which was approximately the average grain-setting in the intra-species crosses made that season. Full germination was obtained and the F_1 seedlings were so healthy and vigorous as almost to make one doubt their hybridity. Their rust reactions, however, showed them to be certainly crosses. The flag smut tests were equally conclusive. After transplanting to the open field, these crossbreds showed astonishing vigour in the midst of many other crossbreds which were weak and yellow. At maturity the plants were normal in development (Plate iii). The leaves were dark green, tillering abundant and heads of normal size. A general intermediacy of characters in relation to the parents was exhibited.

Heads of each of the three crosses were bagged to ensure self-pollination. A little less than 1% of grain set in these heads. Back-crosses with the *vulgare* parents gave a slightly higher fertility and this was still higher when the F_1 plants were pollinated with "Bobin" and "Florence".

Most of the heads were open-pollinated. The results from the harvest are shown in Table 2, and typical heads are illustrated in Plate iv.

TABLE 2.

Grain setting in crosses between three *vulgare* wheats and "Khapli" emmer.

Parents of Cross.	Number of F_1 Plants Counted.	Number of Grains Set.	Number of Flowers Present.	Percentage Grain-Setting.
Garra × Khapli	15	1,153	8,769	13.2
Improved Steinwedel × Khapli	11	1,105	4,522	22.2
Steinwedel × Khapli	13	1,307	6,804	19.1
Totals	39	3,565	20,095	

There is an average grain-setting of 17.2%. This grain varies from shrivelled to normal plump grain, as shown in Plate IV.

When compared with the weakly plants and insignificant fertility obtained by the use of other *vulgare* parents, this is a remarkable result.

In the 1932 season the same crosses were repeated, together with a number of others in which the *vulgare* parent has in its pedigree one or other of the three wheats used so successfully. Unusually good grain-setting has been obtained from some of these.

It seems probable that this capacity of the three *vulgare* wheats to cross with "Khapli" will have a wider application. There are other refractory wheats in addition to "Khapli", having 14 pairs of chromosomes and crossing only with difficulty (if at all) with "Federation" and other *vulgare* wheats. As examples, "Gaza", "Beladi", and "Iumillo" might be cited. In 1932 these were crossed with "Garra", "Improved Steinwedel", and "Steinwedel", and an unusually high setting of plump grain has been obtained. In crosses with rye, however, the same success has not been maintained.

The three *vulgare* wheats are related. "Garra" comes from a cross involving "Steinwedel", as does also "Improved Steinwedel". The other wheats which enter into their pedigrees give sterile, or almost sterile F_1 plants when crossed with "Khapli". "Steinwedel" is a selection from "Champlain's Hybrid". Efforts have been made to secure a sample of this wheat, but have failed. Cytological studies are therefore planned using "Steinwedel" as a basis.

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Summary.

More than 5,000 crosses between *vulgare* wheats and "Khapli" emmer have been made. An average of about 35% grain-setting has resulted. Almost always sterility has been shown by the progeny, but in a few cases a low measure of fertility has been found. Some of these derivatives are now in the F_3 generation.

A big advance comes from crosses made in 1931. The *vulgare* wheats known as "Garra", "Improved Steinwedel" and "Steinwedel" are found to cross readily with "Khapli" and have given F_1 plants of normal development. Under conditions of open-pollination, these hybrid plants have set more than 17% of grain. Crosses between these three *vulgare* wheats and other refractory members of other species of *Triticum* indicate an unusually high fertility in these cases also. Of the three wheats, "Steinwedel" is the one to which this capacity for crossing is traceable.

Literature Cited.

- HAYES, H. K., and STAKMAN, E. C., 1922.—Wheat stem rust from the standpoint of plant breeding. *Proc. Second Ann. Mtg. Canadian Soc. Agron.*, 1921, pp. 997-1012.
- HOLLINGSHEAD, L., 1932.—Partly fertile hybrids of common wheat with Khapli emmer. *Journ. Heredity*, 23, pp. 247-253.
- HYNES, H. J., 1926.—Studies on the reaction to stem rust in a cross between Federation wheat and Khapli emmer, with notes on the fertility of the hybrid types. *Phytopathology*, 16, pp. 809-827.
- McFADDEN, E. S., 1930.—A successful transfer of emmer characters to *vulgare* wheat. *Journ. Amer. Soc. Agron.*, 22, pp. 1020-1034.

- PUTTICK, G. F., 1921.—The reaction of the F_2 generation of a cross between a common and a durum wheat to two biologic forms of *Puccinia graminis*. *Phytopathology*, 11, pp. 205-213.
- THOMPSON, W. P., and HOLLINGSHEAD, L., 1927.—Preponderance of *dicoccum*-like characters and chromosome numbers in hybrids between *Triticum dicoccum* and *T. vulgare*. *Journ. Genetics*, 17, pp. 283-307.
- WATERHOUSE, W. L., 1930.—Australian Rust Studies, III. Initial results of breeding for rust resistance. *Proc. Linn. Soc. N.S.W.*, 55, pp. 596-636.

EXPLANATION OF PLATES III-IV.

Plate iii.

A.—Group of plants of (Steinwedel \times Khapli) at flowering time. Some of the strongly chlorotic and stunted plants of other sterile crosses may be seen in the foreground. Scale in feet at right of picture.

B-F.—Single plants of wheats grown under similar conditions and harvested at maturity. B.—“Khapli”. C.—“Steinwedel”. D.—Fertile F_1 plant of (Steinwedel \times Khapli). E.—Fertile F_1 plant of (Improved Steinwedel \times Khapli). F.—Fertile F_1 plant of (Garra \times Khapli). Scale next to fig. C is one metre long.

G.—Grain produced by one of the F_1 plants of (Garra \times Khapli). Natural size.

Plate iv.

A-G.—Pairs of heads of typical wheat plants grown under similar conditions and shown half natural size. A.—“Khapli”. B.—“Steinwedel”. C.—“Improved Steinwedel”. D.—“Garra”. E.— F_1 plant of (Steinwedel \times Khapli). F.— F_1 plant of (Improved Steinwedel \times Khapli). G.— F_1 plant of (Garra \times Khapli).

H-N.—Two pairs of glumes from contiguous spikelets of wheat heads. Natural size. H.—“Khapli”. I.—“Steinwedel”. J.—“Improved Steinwedel”. K.—“Garra”. L.— F_1 plant of (Steinwedel \times Khapli). M.— F_1 plant of (Improved Steinwedel \times Khapli). N.— F_1 plant of (Garra \times Khapli).

O-Q.—Grain produced by pollinating three *vulgare* wheats with pollen of “Khapli”. Natural size. O.—(Steinwedel \times Khapli). P.—(Improved Steinwedel \times Khapli). Q.—(Garra \times Khapli).